Effect of initial spacing and thinning on lumber grade, yield, and strength of loblolly pine

Alexander Clark, III
Joseph R. Saucier
V. Clark Baldwin
David R. Bower

Abstract

The effect of initial spacing and thinning on grade, strength, and volume of lumber produced from loblolly pine (*Pinus taeda* L.) in southwest Louisiana was examined. Plots planted at spacings of 6 by 6, 8 by 8, 9 by 9, 10 by 10, and 12 by 12 feet were thinned to residual basal areas of 60, 80, 100, and 120 ft.^{2}/acre at age 18 and at 5-year intervals through age 38. Trees thinned from the plots at age 38 were processed into lumber. Based on study tree data, equations were developed to predict total lumber volume and volume of No. 2 and better lumber produced from individual trees. A simulated final harvest at age 38 showed plots planted at 6 by 6 feet and thinned to ≤ 100 ft.^{2}/acre produced ≥ 60 percent No. 2 and better lumber compared to ≤ 42 percent No. 2 and better lumber from plots planted 12 by 12 feet and thinned to the same basal area.

Southern pine lumber graded No. 2 and better generally sells for 45 percent more than lumber graded No. 3 or No. 4. Such a difference in dollar value will be increasingly important in future plantation management decisions as the timber industry experiences further declines in available natural stands and relies more and more on plantations. No existing decision models for southern pine contain the ability to include wood quality differentials in predicted volumes.

Initial planting density and thinning are silvicultural tools that can influence wood properties and, thus, the quality of lumber produced. This paper examines the effect of initial spacing and periodic thinning on the grade, strength, and volume of lumber produced at age 38 from loblolly pine (*Pinus taeda* L.) in southwest Louisiana.

Size and frequency of knots and volume of juvenile wood are important wood properties that influence the desirability of wood for lumber. Large knots and juvenile wood reduce lumber value because they weaken the lumber and make it more prone to warp, creating problems for manufacturers and consumers. Juvenile wood is a cylinder of wood surrounding the pith where xylem cells are formed by immature cambium. The prolonged influence of the apical meristem in the active crown is thought to be responsible for juvenile wood formation since, regardless of tree age, juvenile wood is formed in that portion of the stem that contains young live crown (17). The properties of juvenile wood and their adverse effects on product quality and yield have been reported by many researchers (2,3,16,21,24,26).

The number of years southern pines produce juvenile wood is more highly correlated with environmental factors that are associated with geographic location than genetic differences inherent among species (9). The duration of juvenility in planted pine is not influenced by initial spacing, but the diameter of the juvenile core is significantly correlated with initial spacing (9). Trees planted at wide spacings grow more rapidly during their early years than trees planted at close spacings, thus they contain a larger diameter of juvenile wood. Recent studies of the influence of

The authors are, respectively, Wood Scientist and retired Wood Scientist, USDA Forest Serv., Southeastern Forest Expt. Sta., Forestry Sciences Lab., Athens, GA 30602; Forest Biometrician, USDA Forest Serv., Southern Forest Expt. Sta., Pineville, LA 71360; and Forest Biometrician, Weyerhaeuser Co., Hot Springs, AR 71902. This paper was received for publication in April 1994.

Forest Prod. J. 44(11/12):14-20.

juvenile wood on the strength of dimension lumber show that some lumber cut from the juvenile zone of young fast-grown plantation pine may not meet design requirements (12,15,18).

Early attempts to incorporate wood quality in growth and yield models have been made for coast Douglas-fir (*Pseudotsuga menziesu* (Mich.) Franco var. *menziesu*) (7,13). The approach links stem growth and yield models with crown dynamics to predict location and size of branches. A similar approach has been used for Scots pine (*Pinus sylvestris*) in Finland (25). There are no similar attempts to incorporate wood quality into growth and yield models for southern pine.

The importance of controlling branch size and juvenile wood content by regulating initial spacing and thinning is illustrated in recent lumber yield studies. In a study conducted by MacPeak et al. (12), lumber produced from 20-year-old slash pine planted 12 by 12 feet (302 trees per acre (TPA)) and thinned to 250 TPA was compared to lumber cut from 50-year-old slash pine planted 6 by 6 feet (1,210 TPA) and thinned at ages 12, 20, 25, and 35 to a final density of 245 TPA. The 20-year-old trees had an average diameter at breast height (DBH) of 14.3 inches and the 50-year-old trees averaged 15.1 inches DBH. Only 38 percent of the lumber cut from the 20-year-old trees was graded No. 2 and better, while 69 percent of the lumber cut from the 50-year-old trees was graded No. 2 and better. In another study, Biblis (4) reported that 92 percent of the dimension lumber cut from 27-year-old slash pine planted 6 by 6 feet and thinned only slightly at age 15 was No. 2 and better lumber.

Several researchers have reported the optimal economic planting density based on production of multiple products (pulpwood, chip- n-saw, sawtimber) but not based on the grade yield of these products. Some researchers (1,5,11,19) have used growth and yield models while others (6,10) have reported on actual experimental yield studies. No agreement exists in the literature on optimal planting density because each management plan must consider marketing objectives and all costs associated with stand establishment, management, and harvesting.

Bowling (6) found densities as low as 400 TPA were optimum when marketing chip-n-saw and sawtimber from unthinned slash pine (*P. elliottii* Engelm). Conrad et al. (10) also found that when multiple products are produced from unthinned stands, the wider spacing of 9 by 10 feet (484 TPA) produced the highest economic return, assuming the wide spacing did not affect stem quality. When variable costs for stand establishment, management, and harvesting are considered, Borders et al. (5) reported optimal planting densities for unthinned stands range from 590 to 1,100 TPA. Bailey (1) also found high densities (≥ 1,000 TPA) optimal for unthinned stands.

Broderick et al. (8) found that planting at wide spacings of 10 by 10 feet (436 TPA), thinning at age 15 to 25 (depending on site index), and harvesting at age 26 to 30 yields the optimal return. Planting densities of 750 to 950 TPA combined with thinning at about age 15 led to the highest economic return based on an analysis reported by Hotvedt and Strake (11).

The scheduled thinning of the study plantation was designed to determine the effect of initial spacing and subsequent thinning levels on stand dynamics, growth, and long-term production and provided a unique opportunity to examine the effect of these treatments on lumber grade yield and strength.

Procedures

Study plantation

The study plantation is located on a cut-over longleaf pine (*P. palustris* Mill) site near Merryville in southwest Louisiana. Site preparation involved removing stumps and burning. In January 1952, the 80-acre study site was machine-planted at spacings of 6 by 6 feet (1,210 TPA), 8 by 8 feet (681 TPA), 9 by 9 feet (538 TPA), 10 by 10 feet (436 TPA), and 12 by 12 feet (302 TPA). Planting in strips 2 chains wide and 20 chains long resulted in 4 replications of each spacing (14).

At age 18, the long narrow spacing strips were divided into 0.4-acre thinning plots (2 by 2 chains). Thinning levels with residual densities of 60, 80, 100, and 120 $ft.^2$/acre were assigned at random to each plot. Measurement plots were 0.1 acre and surrounded by a buffer strip 0.5 chain wide. Each plot was thinned back to its assigned residual basal area at age 18, 23, 28, 32, and 38. Generally, thinning was from below. Large dominants were only cut when they were extremely rough or defective, badly forked, or diseased and when their removal helped adjacent dominants. The DBH for each tree and total height and crown height for a stratified sub-sample of trees based on DBH were measured on the measurement plots and recorded before and after each thinning.

Sample trees

A total of 307 trees, ≥ 9.0-inch DBH with a minimum of one 16-foot sawlog to a 6.0-inch diameter inside bark (d.i.b.) top, were thinned from the study plots at age 38 and processed into lumber. Sixty-five of the trees were selected from the measurement plots and the others were selected from plot buffers. Trees thinned from the measurement plots were selected using the thinning criteria described. Trees selected for thinning from the buffer of each plot were selected randomly within DBH classes to simulate a final harvest.

The DBH of the sample trees ranged from 9.0 to 17.4 inches and averaged 79 feet in total height. The trees were felled with chainsaws and bucked into sawlogs 8 to 16 feet long on site. Nine to 21 trees were

TABLE 1. — *Average diameter at breast height (DBH) and total height of 38-year-old loblolly pine trees processed into lumber by spacing and residual basal area.*

	Residual basal area per acre (ft.^{2})											
	60			80			100			120		
Initial spacing	No. of trees sampled	DBH	Total height	No. of trees sampled	DBH	Total height	No. of trees sampled	DBH	Total height	No. of trees sampled	DBH	Total height
(ft.)		(in.)	(ft.)		(in.)	(ft.)		(in.)	(ft.)		(in.)	(ft.)
6 by 6	18	12.4	81	18	11.5	77	14	11.5	81	20	11.0	82
8 by 8	18	13.0	80	21	12.0	79	10	10.5	78	20	11.2	80
9 by 9	16	12.7	81	21	11.6	76	16	11.7	82	9	11.1	82
10 by 10	20	12.6	78	17	12.6	77	18	11.4	77	10	11.4	80
12 by 12	16	13.9	81	14	12.8	79	11	12.4	81	- -	- -	- -

sampled from each spacing/thinning combination (Table 1). The sawlogs harvested from the 6- by 6-, 9- by 9-, and 12- by 12-foot plots were weighed with bark to ± 2.0 lb. at the logging deck.

Sawing and lumber grading

The 1,033 logs harvested were trucked to Weyerhaeuser Company sawmills near Hot Springs, Ark., and sawn into 4/4 boards and 2 by 4, 2 by 6, and 2 by 10 dimension lumber. Logs < 10.0 inch scaling diameter were processed at a chipping-sawmill and logs ≥ 10.0 inch scaling diameter were processed at a band mill.

Examination of the cross sections of the butt logs from the spacing and thinning plots showed the length of juvenility to be 10 years. A red circle representing the first 10 rings from the pith was painted on each end of the 193 bandsaw logs. The logs processed in the band mill produced 1,982 pieces of lumber. After sawing, the proportion of each end of each piece of lumber produced in the band mill that was juvenile wood was estimated and recorded.

Lumber cut from each log was identified, dried, and then graded by certified Southern Pine Inspection Bureau (SPIB) lumber graders (23) after planing. A random subsample of dimension lumber graded No. 2 and better was machine stress rated (MSR) on a continuous lumber testing machine to nondestructively determine average modulus of elasticity (AMOE) and low-point modulus of elasticity (LMOE) in million psi.

The MSR lumber was placed into one of two SPIB MSR grade classifications (22) based on the following criteria:

Grade classification	AMOE	LMOE
	(million psi)	
1650F-1.5E	≥ 1.4 and < 1.6	≥ 1.2 and < 1.4
2100F-1.8E	≥ 1.6	≥ 1.4

Analysis

The proportion of juvenile wood recorded for each end of each piece of lumber cut from each bandsaw log was averaged. Correlation coefficients were developed to show the relationship between juvenile wood content and AMOE and LMOE for the 2 by 4 and 2 by 6 lumber cut from the bandsaw logs. The strength of the lumber, proportion of juvenile wood, and volume of lumber by grade were summarized for logs and trees by treatments. Regression equations were developed to predict total lumber volume and volume of No. 2 and better lumber produced from a tree. Equations were also developed to predict tree sawlog stem wood volume and wood and bark green weight. The following linear model was used:

$$Y = a + b\,(D^2 \times TH) + c\,(RBA) + d\,(D^2 \times TH \times INTA)$$

where:

Y = total lumber volume for all grades (board feet (BF)), volume of all lumber graded No. 2 and better, sawlog stemwood volume (ft.^{3}), or sawlog stemwood and bark green weight (lb.)
D = tree DBH (in.)
TH = tree total height (ft.)
RBA = residual basal area (ft.^{2}/acre)
INTA = initial number of trees per acre at stand establishment

The prediction equations were applied to trees ≥ 9.0 inch DBH, tallied on each measurement plot before thinning at age 38, and expanded to yields per acre.

The average lumber prices in the South as of January 1993 (20) were used to obtain an average lumber value of $357 per thousand BF (MBF) for No.

TABLE 2. — *Effect of initial spacing and thinning to residual basal area after age 18 on perce ntage of lumber classed as juvenile wood for loblolly pine in the coastal plain of Louisiana.*

Initial spacing	Residual basal area per acre (ft.^{2})			
	60	80	100	120
(ft.)	(%)			
6 by 6	32	38	39	43
8 by 8	34	37	- -[a]	34
9 by 9	35	35	41	42
10 by 10	36	39	42	44
12 by 12	39	41	49	- -

[a] No bandsaw logs were processed.

2 and better and \$243/MBF for No. 3 and worse. These values were obtained by weighting lumber grade prices in proportion to the average yield by grade for this study. The volume of No. 3 and worse lumber for each tree was determined by subtracting the predicted volume of No. 2 and better from the predicted total lumber volume.

An analysis of variance (ANOVA) was performed on plot summaries to determine the effects of spacing and thinning on sawlog volume, sawlog weight, proportion of lumber produced that was grade 2 or better, value per MBF, and total value of lumber produced at age 38. The ANOVA was performed assuming a completely randomized design and assuming spacing strips were whole plots in a split-plot design. The results of the split-plot analysis were similar to the randomized analysis, but are not reported because the strips were not complete blocks.

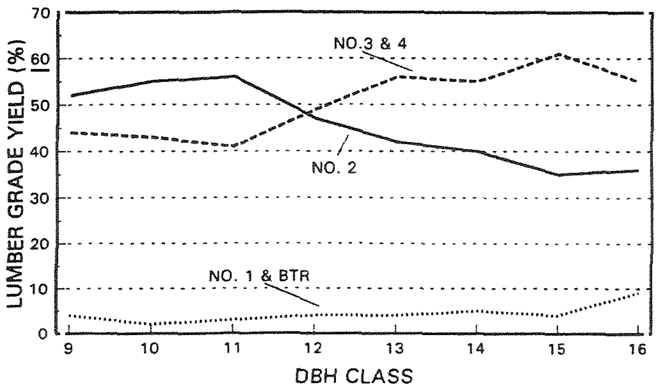

Figure 1. — Effect of tree size averaged across spacing and thinning treatments on proportion of lumber graded No. 1 and better (BTR), No. 2, and No. 3 and 4 for loblolly pine sawn at age 38 on the coastal plain of Louisiana.

Results and discussion

The 307 trees harvested produced 193 band mill logs and 736 chip-n-saw logs. The band mill logs averaged 10.9-inch scaling diameter and produced 15,959 BF of lumber. The chipping sawlogs were an average 7.8-inch scaling diameter and produced 35,128 BF of lumber.

Initial spacing and thinning to different residual basal areas after age 18 affected the volume of juvenile

TABLE 5. — *Effect of initial spacing and thinning to residual basal area after age 18 on percentage of lumber produced per acre that is grade No. 2 and better from simulated clearcut at age 38 for loblolly pine in the coastal plain of Louisiana.*

	Residual basal area per acre (ft.^{2})			
Initial spacing	60	80	100	120
(ft.)	(%)			
6 by 6	62	63	60	55
8 by 8	49	53	50	48
9 by 9	47	49	45	43
10 by 10	49	46	45	42
12 by 12	42	42	38	- -

TABLE 3. — *Regression equations and coefficients for estimating total lumber volume, volume of No. 2 and better lumber, sawlog stemwood volume and sawlog stemwood and bark weight for loblolly pine trees planted at various initial spacings and thinned to various residual basal areas after age 18.*

Independent variable (Y)[a]	Regression coefficients *a*	b	c	d	Standard error of estimate	Coefficient of determination	Coefficient of variation
Total lumber volume (BF)	-10.50517	0.01398	-0.08852	0.000001009	22.8	.87	14.8
No. 2 and better lumber volume (BF)	42.36675	0.00033	-0.28646	0.000002803	33.4	.34	43.0
Sawlog stem volume (ft.^{3})	- 1.68678	0.00189	-0.01160	0.000000101	2.4	.92	11.7
Sawlog stem weight (lb.)	12.31959	0.12552	-2.15551	0.000011212	178.0	.92	11.0

[a] $Y = a + b\,(D^2{\times}TH) + c\,(RBA) + d\,(D^2{\times}TH{\times}INTA)$.
where: Y = independent variable
D = tree DBH (in.)
TH = tree total height (ft.)
RBA = residual basal area (ft.^{2}/acre)
INTA = initial number of trees per acre.

TABLE 4. — *Number of sawlog trees per acre, average diameter at breast height (DBH), sawlog stemwood volume, and lumber volume per acre for a simulated harvest of all sawtimber trees at age 38 by initial spacing and residual basal area for loblolly pine in the coastal plain of Louisiana.*

	Residual basal area per acre (ft.^{2})															
	60				80				100				120			
Initial spacing	No. of trees per acre	Avg. DBH	Sawlog volume	Stem weight	No. of trees per acre	Avg. DBH	Sawlog volume	Stem weight	No. of trees per acre	Avg. DBH	Sawlog volume	Stem weight	No. of trees per acre	Avg. DBH	Sawlog volume	Stem weight
(ft.)		(in.)	(cunit/acre)[a]	(ton/acre)		(in.)	(cunit/acre)	(ton/acre)		(in.)	(cunit/acre)	(ton/acre)		(in.)	(cunit/acre)	(ton/acre)
6 by 6	84	12.3	18.5	66	126	11.3	21.9	77	142	11.0	25.1	86	158	11.1	28.6	96
8 by 8	70	13.2	17.6	61	113	11.8	21.6	75	158	11.3	28.1	95	170	11.0	28.4	93
9 by 9	72	13.7	20.2	70	110	12.2	21.8	74	128	12.0	26.9	90	154	11.7	30.8	102
10 by 10	76	13.0	17.2	60	95	12.8	20.9	72	129	12.0	25.3	85	163	11.6	29.4	96
12 by 12	60	14.7	19.4	66	90	13.5	23.3	79	110	13.8	31.3	104	- -	- -	- -	- -

[a] One cunit = 100 ft.^{3}

wood (Table 2). Stands planted at close spacings (6 by 6 or 8 by 8 ft.) and thinned to 60 ft.^{2}/acre produced lumber with 32 to 34 percent juvenile wood compared to stands planted at wide spacings (10 by 10 or 12 by 12 ft.) and thinned to 100 to 120 ft.^{2}/acre, which produced lumber containing 42 to 49 percent juvenile wood.

During the early years of a plantation when juvenile wood is produced in what will become the first and second logs, trees planted at close spacings put on less radial growth than those planted at wider spacings. Following thinning, heavily thinned stands put on more radial growth than lightly thinned stands. Thus, stands planted close and then heavily thinned contain a smaller core of juvenile wood than stands planted at wider spacings and lightly thinned.

The effect of tree size on lumber grade yield is shown in Figure 1. As DBH increased, the proportion of lumber graded No. 1 and better increased slightly; the proportion graded No. 2 decreased; and the proportion graded No. 3 or worse increased.

To examine the effect of initial spacing and thinning to residual basal area after age 18 on lumber grade yield, a harvest of sawtimber trees at age 38 was simulated. Regression equations were developed to predict sawlog stem wood volume, sawlog stem weight, total volume of lumber, and volume of lumber graded No. 2 and better (Table 3). They were applied to every tree ≥ 9.0 inches DBH on each measurement plot and plot estimates expanded to treatment averages per acre.

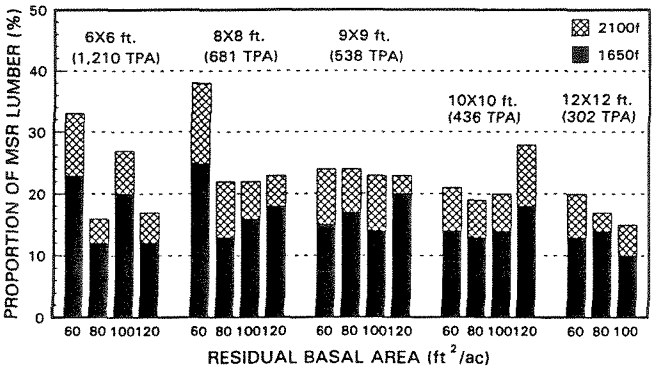

Figure 2.— Effect of initial spacing and thinning to residual basal area after age 18 on the proportion of No. 2 and better, machine stress-rated, 2 by 4 lumber that graded 2100F and 1650F for 38-year-old loblolly pine in the coastal plain of Louisiana.

At age 38, the number of sawtimber trees ranged from 60 TPA with an average 14.7-inch DBH from the 12- by 12-foot plots thinned to 60 ft.^{2}/acre, to 170 TPA with an average 11.0-inch DBH from the 8- by 8-foot plots thinned to 120 ft.^{2}/acre (Table 4). The sawlog volumes and stem weights increased significantly (p = .001) with an increase in residual basal area per acre, but were not significantly affected by initial spacing. Sawlog volumes ranged from an average of 18.6 cunits (100 ft.^{3})/acre for a residual basal area of 60 ft.^{2} to 29.3 cunits/acre for a residual basal area of 120 ft.^{2} (+58%)). Stem weights ranged from an average of 64.6 tons/acre for a basal area of 60 ft.^{2} to 98.5 tons/acre for a basal area of 120 ft.^{2} (+50%).

Both initial spacing and thinning to different residual basal areas after age 18 had a significant effect (p = .001) on the proportion of lumber per acre graded No. 2 and better (Table 5). Plots planted at spacings of 6 by 6 feet and thinned to ≤ 100 ft.^{2}/acre produced the highest proportion of No. 2 and better lumber (60% to 63%). Plots planted at spacings of 12 by 12 feet and thinned to the same residual basal areas produced the lowest proportion of No. 2 and better lumber (38% to 42%). Wider initial spacing reduced the proportion of No. 2 and better lumber more than maintaining higher residual basal areas.

These differences in lumber grade yield occurred because trees in plots with relatively close initial spacing had fewer and smaller branches than trees in plots planted at 12- by 12-foot spacing. After thinning,

TABLE 6. — *Effect of initial spacing and thinning to residual basal area after age 18 on value per thousand board feet (MBF) for lumber produced per acre in simulated clearcut at age 38 for loblolly pine in the coastal plain of Louisiana.*

Initial spacing	Residual basal area per acre (ft.^{2}) 60	80	100	120
(ft.)	($/MBF)			
6 by 6	315	315	311	306
8 by 8	299	303	300	297
9 by 9	296	299	295	292
10 by 10	299	296	294	291
12 by 12	290	291	287	- -

TABLE 7. — *Effect of initial spacing and thinning to residual basal area after age 18 on volume and value per acre of lumber produced from trees harvested in simulated clearcut at age 38 for loblolly pine in the coastal plain of Louisiana.*

	Residual basal area per acre (ft.^{2})							
	60		80		100		120	
Initial spacing	Volume	Value	Volume	Value	Volume	Value	Volume	Value
(ft.)	(MBF/acre)	($)	(MBF/acre)	($)	(MBF/acre)	($)	(MBF/acre)	($)
6 by 6	14.1	4,434	16.8	5,302	19.2	5,982	21.9	6,705
8 by 8	13.3	3,974	16.5	4,989	21.3	6,403	21.6	6,417
9 by 9	15.2	4,506	16.5	4,925	20.3	5,997	23.3	6,814
10 by 10	12.9	3,882	15.7	4,659	9.1	5,629	22.2	6,468
12 by 12	14.5	4,217	17.5	5,093	23.5	6,732	- -	- -

trees planted at close spacing produced clear mature wood along the lower bole, but trees in the widely spaced 12- by 12-foot plots had persistent lower branches that continued to increase in size, leading to large knots in manufactured lumber. Because 2 by 4 and 2 by 6 lumber graded No. 2 cannot have any knots > 2-7/8 inches, silvicultural practices favoring production of large-diameter branches reduce lumber grade yield.

On average, the No. 2 and better lumber processed through the continuous stress testing machine was relatively weak, with only 23 percent in either the 1650F or the 2100F MSR classifications (22). In the 2 by 4 category, only 7 percent of the 1,173 pieces tested made the 2100F classification and only 16 percent made the 1650F classification. These low MSR grade yields are directly related to the LMOE values of the pieces. If the LMOE criteria were not applied, 45 percent of the lumber tested would be classified as 1650F, indicating that knots close to the maximum size permitted in No. 2 boards or other strength-affecting defects are responsible for the low range of the LMOE.

Plots planted at 6 by 6 or 8 by 8 feet and thinned to 60 ft.^{2}/acre yielded the highest proportion of lumber classified as 1650F or 2100F while plots planted at 12 by 12 feet yielded the lowest proportion of lumber in the 1650F and 2100F classification (Fig. 2). The closely planted, heavily thinned plots produced a higher proportion of stronger lumber because the trees had smaller knots in the lower bole and less juvenile wood. The AMOE of the pieces tested were significantly correlated (r = 0.46) with percent juvenile wood content.

Table 6 shows the effect of the spacing and thinning treatments on the value per MBF of lumber produced. Value per MBF decreased significantly (p = .001) with increasing basal area and decreased significantly (p = .003) with increased spacing. Planting at initial close spacings of 6 by 6 feet and thinning to residual basal areas of 60 to 120 ft.^{2}/acre after age 18 yielded more greater value lumber than any other spacing and thinning combination. For example, plots planted with a 6- by 6-foot spacing and thinned to 60 or 80 ft.^{2}/acre basal area yielded lumber valued at about 10 percent more per MBF than lumber produced from thinned 12- by 12-foot plots.

When the value of all lumber produced is examined on a per-acre basis rather than an MBF basis, treatments associated with high lumber volume per acre resulted in the highest value of lumber produced (Table 7). The value of all lumber produced at age 38 increased significantly (p = .001) with increased basal area. For example, plots thinned to 60 ft.^{2}/acre, on average, produced 14.0 MBF/acre at age 38, with a lumber value of $4,203/acre, while plots thinned to 120 ft.^{2}/acre produced 22.2 MBF/acre at age 38, with an average value of $6,601/acre (+57%). Initial spacing had no significant effect on standing volume at age 38 and, thus, no significant effect on value per acre at age 38. The costs and values of the Merryville study management system from stand establishment to harvest will be addressed in a separate paper.

Conclusions

Initial planting density and thinning to residual basal area after age 18 significantly affected the wood properties and quality of lumber produced from a loblolly pine stand at age 38. Plots planted at spacings of 6 by 6 feet and thinned to 100 ft.^{2}/acre produced 60 percent No. 2 and better lumber. Plots planted at 12- by 12-foot spacings and thinned to the same basal area yielded 42 percent No. 2 and better lumber. The lumber value per MBF was about 10 percent higher for the 6- by 6-foot plots thinned to 100 ft.^{2}/acre than for the 12- by 12-foot plots thinned to the same residual basal area. On a per-acre basis, however, plots thinned to leave the highest residual basal area produced the highest volume and value per acre.

These results illustrate that growth and yield models need to account for not only changes in wood volume but also changes in wood properties related to stand management decisions. Modeling for wood properties is difficult because of the many variables that influence wood formation. Substantial additional research is needed to develop wood property models for inclusion into existing southern pine growth and yield packages. Based on these results, such models should incorporate the effect of initial planting density and thinning regimes on product grade yields.

Literature cited

1. Bailey, R.L. 1986. Rotation age and establishment density for planted slash and loblolly pines. Southern. J. Appl. Forestry 10:162-168.
2. Bendtsen, B.A. 1978. Properties of wood from improved and intensively managed trees. Forest Prod. J. 28(10):61-72.
3. ________. 1987. Quality impacts of the changing timber resource on solid wood products. *In*: Proc. 47349, Managing and Marketing the Changing Timber Resource. Forest Prod. Res. Soc., Madison, Wis. pp. 44-57.
4. Biblis, E.J. 1990. Properties and grade yield of lumber from a 27-year-old slash pine plantation. Forest Prod. J. 40(3):21-24.
5. Borders, B.E., W.D. Green, and M.L. Clutter. 1991. Variable bedding, planting, harvesting and transportation costs impact optimal economic management regimes. Southern J. Appl. Forestry 15:38-43.
6. Bowling, D. 1986. Twenty-year slash pine spacing study: What to optimize? *In*: Proc. Fourth Biennial Southern Silvicultural Res. Conf, USDA Forest Serv. Gen. Tech. Rept. SE-42. pp. 300-304.
7. Briggs, D.G. and R.D. Fight. 1991. Modeling the interaction of silvicultural practices, wood quality and product value in Douglas-fir. *In*: Proc. Soc. of Am. Forestry 1991 Annual Conv. pp. 86-91.
8. Broderick, S.H., J.F. Thurmes, and W.D. Klemperer. 1982. Economic evaluation of old-field loblolly pine plantation management alternatives. Southern J. Appl. Forestry 6:1-15.
9. Clark, A. III and J.R. Saucier. 1989. Influence of initial planting density, geographic location, and species on juvenile wood formation in southern pine. Forest Prod. J. 39(7/8):42-48.
10. Conrad, L.W. III, T.J. Straka, and W.F. Watson. 1990. Economic evaluation of initial spacing for a thirty-year-old unthinned loblolly pine plantation. Poster session and manuscript presented at Soc. Am. Forestry 1990 Annual Conv. 15 pp.
11. Hotvedt, J.E. and T.J. Straka. 1987. Using residual values to analyze the economics of southern pine thinning. Southern. J. Appl. Forestry 11:99-106.
12. MacPeak, M.D., L.F. Burkhart, and D. Weldon. 1990. Comparison of grade, yield, and mechanical properties of lumber pro-

duced from young fast-grown and older slow-grown planted slash pine. Forest Prod. J. 40(1):11-14.
13. Maguire, D.A. 1991. Strategies for modeling the effect of silvicultural regime on wood quality in Douglas-fir. *In:* Proc. Soc. Am. Forestry 1991 Annual Conv. pp. 80-85.
14. Mann, W.F., Jr. and T.R. Dell. 1971. Yields of 17-year-old loblolly pine planted on a cutover site at various spacings. USDA Forest Serv. Res. Pap. SO-70. 9 pp.
15. McAlister, R.H. and A. Clark, III. 1991. Effect of geographic location and seed source on the bending properties of juvenile and mature loblolly pine. Forest Prod. J. 41(9):1-4.
16. Megraw, R.A. 1985. Wood quality factors in loblolly pine. TAPPI Press. 88 pp.
17. Panshin, A.J. and C. de Zeeuw. 1980. Textbook of Wood Technology. 4th ed. McGraw-Hill, New York. 722 pp.
18. Pearson, R.G. 1988. Compressive properties of clear and knotty loblolly pine juvenile wood. Forest Prod. J. 39(7/8):15-22.
19. Pienaar, L.V. 1977. Analyzing alternative management strategies for unthinned plantations. Southern J. Appl. Forestry 2:26-32.
20. Random Lengths Publications. 1993. Random lengths lumber/market price report, Jan. 8, 1993.
21. Senft, J.F., M.J. Quanci, and B.A. Bendtsen. 1986. Property profile of 60-year old Douglas-fir. *In:* Proc. 473499, Juvenile Wood: What does it mean to forest management and forest products? Forest Prod. Res. Soc., Madison, Wis. pp. 17-28.
22. Southern Pine Inspection Bureau. 1991. Standard grading rules for southern pine lumber. SPIB, Pensacola, Fla. 134 pp.
23. ________. 1977. Grading rules. SPIB, Pensacola, Fla. 218 pp.
24. Thomas, R.J. 1984. The characteristics of juvenile wood. *In:* Proc. of Symposium on Utilization of the Changing Resource in the Southern United States. R.C. Kellison, ed. North Carolina State Univ., Raleigh, N.C. pp. 40-52.
25. Vaisanen, H., S. Kellomaki, P. Oker-Blom, and E. Valtonen. 1989. Structural development of *Pinus sylvestris* stands with varying initial density; a preliminary model for quality of sawn timber as affected by silvicultural measures. Scandinavian J. of Forest Res. 4(2):223-238.
26. Zobel, B. 1981. Wood quality from fast-grown plantations. Tappi 64(1):71-74.